# CONTRIBUTION OF THE NN INELASTICITY INTO PHOTODISINTEGRATION OF THE DEUTERON

V.A. SADOVNIKOVA
*PNPI, Gatchina, 188350 St.Petersburg*

**Abstract**

The technique of dispersion integration over the mass of composite particle is used to describe the reaction of the deuteron photodisintegration. The influence of the final state interaction (FSI) on the total cross section, calculated with and without inelasticity is investigated. Numerical results depend on the choice of the vertex function for the isobar photoproduction.

The reaction of photodisintegration of the deuteron has been considered in the framework of the dispersion relation approach developed by V.V.Anisovich et al.[1]. This method allows us to construct relativistic and gauge invariant amplitude of the photodisintegration. Besides, in the dispersion technique the condition $p_i^2 = m_i^2$ is fulfilled for all particles in the intermediate state, thus no problem with the determination of the off-mass-shell amplitudes.

To describe photodisintegration amplitude the diagrams shown in Fig.1 have been used.

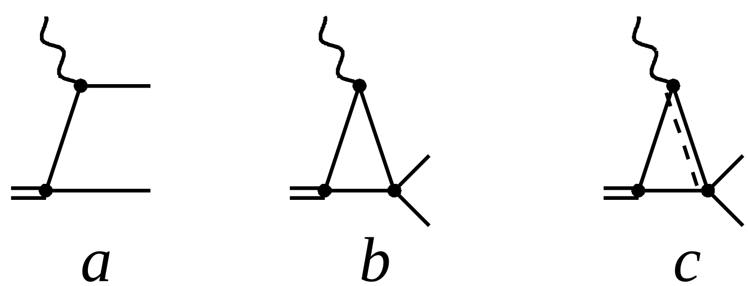


Fig.1.

It should be pointed out that all components of the photodisintegration amplitude have been calculated in the dispersion integration technique: 1) deuteron vertex function which is the relativistic analogue of the deuteron wave function[1]; 2) FSI; its construction is based on the NN scattering amplitude; 3) the amplitudes of diagrams shown in Fig.1.

The main item of our study is the $NN$ scattering amplitude $A(s,t)$. This amplitude has been used to find the deuteron vertex function and FSI[1,2].

Our dispersion relation approach is based on the dispersion $N/D$ method for $A(s,t)$. In this method the partial wave amplitudes are treated. Partial amplitudes, $A_l(s)$, in the $s$-channel depend on $s$ only, they have all $s$-channel singularities of $A(s,t)$ (right hand singularities) and left hand singularities, related to the $t$- and $u$-channel singularities.

The dispersion $N/D$ method provides us an opportunity to construct relativistic two-particle partial amplitude in the region of low and intermediate energies. One can successively include one open channel after another.

$N_l$-functions are presented as a sum of separable terms

$$N_l(s) = G_l(s) \cdot G'_l(s) + \dots , \tag{1}$$

and in our case $G'_l$ differs from $G_l$ in a sign. In the simplest case the equation for the partial scattering amplitude can be written in the form[1,2]

$$A_l = G_l^T (1 - B_l)^{-1} G_l. \tag{2}$$

Here $B_l$ is the dispersion integral for the one-loop diagram:

$$B_l = \int_{4m^2}^{\infty} \frac{ds'}{\pi} \frac{\rho'_l) G_l^2(s')}{s' - s} . \tag{3}$$

Eq.2 is an analogue of Bethe–Salperter equation for separable interaction of a special form.

$G_l$-functions are determined by their left singularities and can be represented as the integrals along the left hand cut

$$G_l(s) = \int_{-\infty}^{s_L} \frac{ds'}{\pi} \frac{discG_l(s')}{s' - s} = \sum_{i=1}^{N_l} \frac{\gamma_{li}}{s - s_{li}} . \tag{4}$$

To simplify numerical calculations the integral can be replaced by a sum. The parameters $\gamma_{li}, s_{li}$ have been found fitting the data of the phase shift analysis. The obtained $G$-functions are used in FSI amplitudes.

In calculations performed in this paper the phase shift analysis of Arndt et al.[3] has been used.

First, the one-channel partial amplitudes, $A_l(s)$, have been calculated. For this case $G$-functions have been constructed fitting NN phase shifts, $\delta_{NN}$, only, and photodisintegration amplitude is defined by two diagrams 1a and 1b.

The phase shift analysis by Arndt et al.[3] reveals the presence of an essential inelasticity in the waves ${}^1S_0$, ${}^3P_0$, ${}^3P_1$, ${}^3P_2$, ${}^1D_2$, ${}^3F_3$ at $T < 1$ GeV ( kinetic energy of the incident proton) .

In the waves ${}^3P_2$, ${}^1D_2$, ${}^3F_3$ the amplitudes have the resonance-type behaviour. This resonance corresponds to the intermediate state $N\Delta$. For these waves the two-channel scattering amplitudes have been built up, and the parameters of $G$-functions have been found by fitting $NN$ and $N\Delta$ phase shifts and the transition amplitudes $|A_{NN-N\Delta}|^2$. So, there is two-channel FSI and photodisintegration amplitude has been calculated using the diagrams 1a, 1b, 1c. In Fig.3b the partial cross section ( defined as shown in Fig.2) for the wave ${}^1D_2$ is demonstrated. By definition this cross section is the contribution of final state interaction to the total cross section for different waves. The main contribution is given by the diagram 1c.

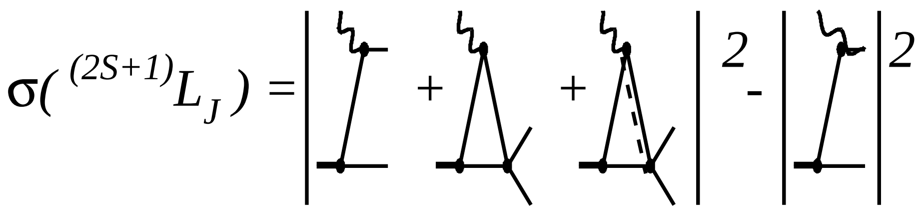


Fig.2.Definition of the partial cross section.

For $^1S_0$, $^3P_0$, $^3P_1$ waves the phase shift analysis gives large inelasticity as well, but without resonances in the amplitudes. Likewise, the two-channel amplitude has been treated, but for the second channel some variants have been tried: $N\Delta$, $NN^*(1440)$, $\pi N$-pair in the relative $S$-wave. To find the parameters, phase shifts $\delta_{NN}$ and the parameter of inelasticity $\rho$ from the paper[3] were fitted. In Fig.3a the partial cross section for the wave $^1S_0$ is demonstrated. The main contribution is due to the rescattering processes in the diagram 1b. The shaded area stands for the different types of inelasticity.

In Fig.4a partial cross sections for the waves $^1S_0$, $^3P_0$, $^3P_1$ are represented, the largest values of the cross sections are for the photon energy $E_\gamma$ <100 MeV.

In Fig.4b partial cross sections for the waves $^3P_2$, $^1D_2$, $^3F_3$ are demonstrated, which give the main contribution in the resonance region. We see that the largest contribution have been obtained from the wave $^3F_3$. In the well-known nonrelativistic approach of Leidemann and Arenhovel[4] the main contribution in this region is due to the interaction with the dipole magnetic external field. $M1$ transition from nucleon to isobar is well known. This corresponds mainly to the $^1D_2$ nucleon-nucleon final state in the diagram 1c.

To understand this, let us turn to the vertex of the isobar photoproduction. In our calculations the operator introduced by Gourdin and Salin[5] has been used

$$\Gamma_{\mu\kappa} = c\gamma_5(\hat{q}g_{\mu\kappa} - q_\kappa\gamma_\mu)\,, \tag{5}$$

q is the photon momentum. In the nonrelativistic limit this expression has a form

$$V(\sigma',\sigma) =< 3/2\sigma'|i(\vec{S}^+[\vec{q},\vec{e}])\left(1-\frac{\delta}{4m}\right) - \frac{\delta}{8m}(\vec{e}T\vec{q}) + P(p_\Delta))|1/2\sigma>\,, \tag{6}$$

$\delta = m_\Delta - m$, $\vec{e}$ is the photon polarization, $\vec{S}^+$ is the transition spin and $T$ is the quadrupole transition operator.

The first term corresponds to the $M1$ transition, the second one to $E2$, and there is a part, $P(p_\Delta)$, which depends on the isobar momentum ($p_\Delta$). Due to $P(p_\Delta)$ the photodisintegration amplitude for the wave $^3F_3$ does not equal to zero.

The operator (5) can be considered as a particular case of the expression given by Bjorken and Walecka[6]. One can tried to check the results using another operator form for the photodisintegration vertex. One of the simplest operators is

$$\Gamma_{\mu\kappa} = ci\varepsilon_{\kappa\mu ab}q_a p_{\Delta b}\,. \tag{7}$$

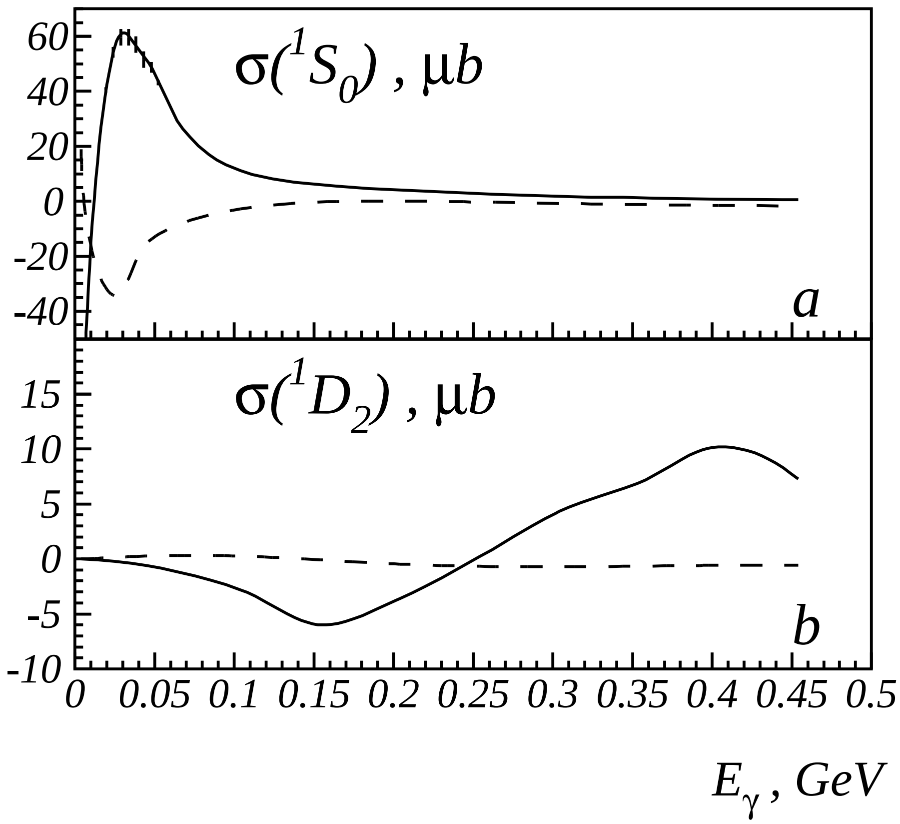


Fig. 3. Partial cross sections calculated with (solid line) and without (dashed) inelasticity: a) $^1S_0$, b) $^1D_2$.

Its nonrelativistic limit is the following

$$V(\sigma', \sigma) =< 3/2\sigma'|i(\vec{S}^+[\vec{q}, \vec{e}]) + \tilde{P}(p_\Delta)|1/2\sigma > , \qquad (8)$$

Coupling constants, $c$, for both cases are calculated with the help of the isobar width[2]. In Fig.5 one can see that the results for partial cross sections differ considerably in these two cases. Calculations with vertex (7) are similar to the nonrelativistic case.

Thus the calculation of partial cross sections with the correct FSI is demonstrated. Special attention should be paid to the appropriate choice of the isobar photoproducton vertex and its form factors.

# 1 Acknowledgements


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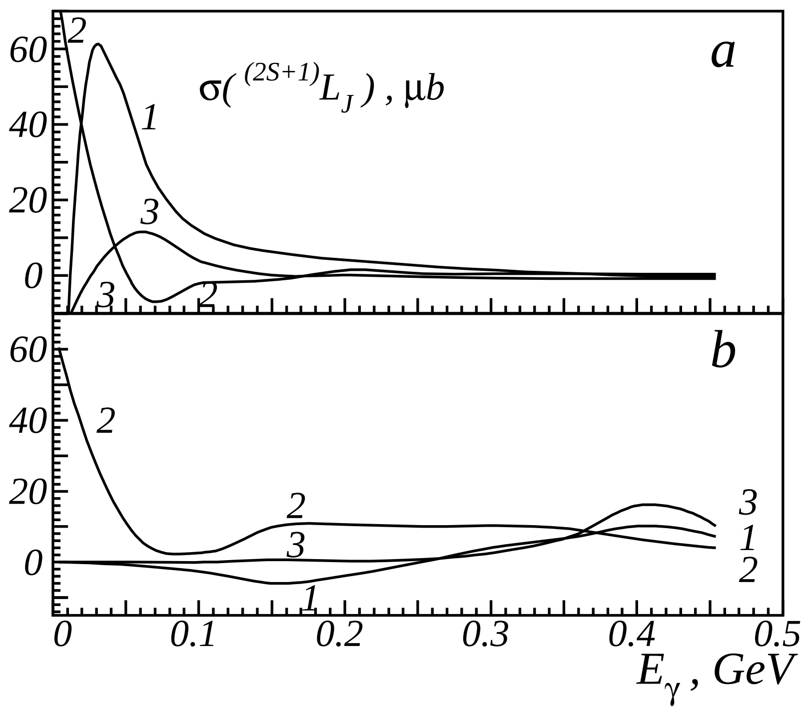


Fig. 4. Partial cross sections for the following waves: a)1: $^1S_0$, 2: $^3P_0$, 3: $^3P_1$; b) 1: $^1D_2$, 2: $^3P_2$, 3: $^3F_3$.


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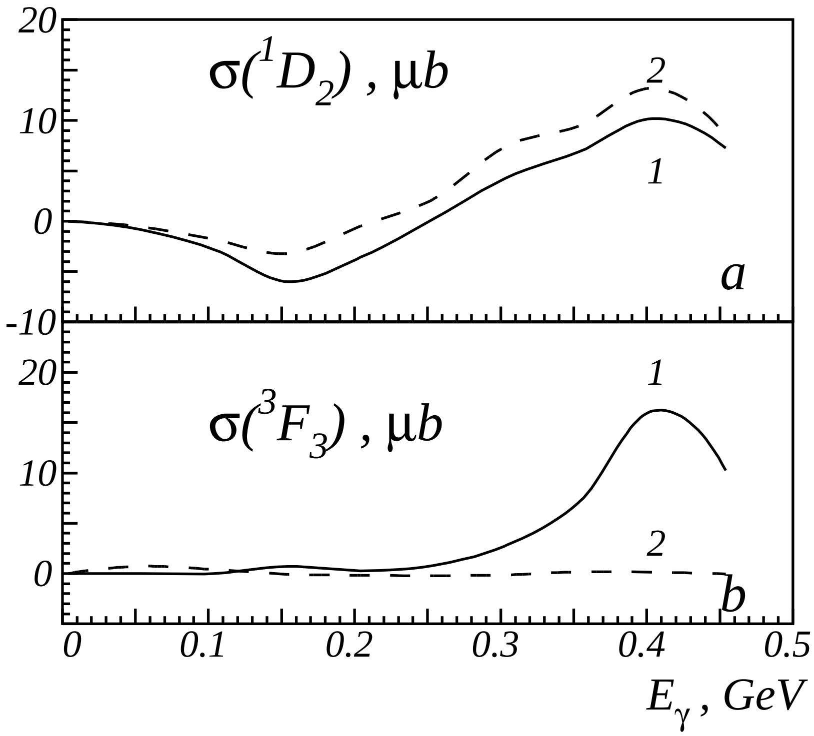


Fig. 5. Partial cross sections calculated with vertex operator (5) (solid) and (7) (dashed): a) $^1D_2$; b) $^3F_3$.